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TECHNICAL NOTE

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STRENGTH TESTS OF SHEAR WEBS WITH UPRIGHTS NOT CONNECTED TO THE FLANGES

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SUMMARY

Results are presented of strength tests of curved and plane shear webs and plane beam webs of 24S-T aluminum alloy stiffened transversely (in the direction of curvature) by uprights that are not connected to the flanges. A method of predicting ultimate strengths based on a modified theory of incomplete diagonal tension in plane webs is given.

INTRODUCTION

Detachable panels on wing surfaces are often stiffened only in the chordwise direction and are attached by screwing the edges of the panels to the wing skin. By the nature of their construction, such panels are loaded primarily in shear, but the usual methods of analyzing shear webs are not applicable because they are valid only when the ends of the stiffeners are attached to longitudinal edge members. This paper presents results of tests of detachable panels and an empirical method of predicting their strengths, based on a modification of the theory of incomplete diagonal tension.

SYMBOLS

A	area enclosed by median line of cross section of torsion box, square inches
R	radius of curvature of sheet, inches
d	spacing of uprights, inches
k	diagonal-tension factor
t	thickness, inches (without subscript signifies thickness of web)

ρ centroidal radius of gyration of cross section of upright about axis parallel to web, inches

τ nominal shear stress, ksi

Subscripts:

U upright

cr critical

ult ultimate

e effective

Special combinations:

A_U cross-sectional area of upright, square inches

A_{U_e} effective cross-sectional area of upright, square inches

L_e reduced "effective" column length (see formula (12) of reference 1)

P_{ult} ultimate force, kips

T_{ult} ultimate torque, kip-inches

h_e depth of beam measured between centroids of flanges, inches

ωd parameter of flange flexibility used in theory of diagonal tension

TEST SPECIMENS

Thirty-nine specimens of three types were tested: plane shear webs, curved shear webs, and plane beam webs. The webs were stiffened transversely (in the direction of curvature), and both webs and stiffeners were made of 24S-T aluminum alloy. For identification of the shear webs a code designation is used such as 4-D-1, which has the following meaning:

4 is the number of the specimen

D stands for double uprights (S, for single uprights)

1 is the approximate "rise" (distance in inches, measured at midchord, from chord to web)

General dimensions of the test specimens are shown in figure 1, and more detailed dimensions are given in table 1. The webs with single uprights represent practical construction; the webs with double uprights were intended for use in obtaining check data for possible future theoretical analysis.

On all the specimens the uprights extended transversely over the web and were cut off a short distance from the flanges, as shown in figure 1. The clear distance between the end of the upright and the flange was $\frac{1}{16}$ inch for the shear webs and $\frac{1}{8}$ inch for the beam webs.

The shear webs were attached to a torsion box and loaded by means of a couple applied at the tip, as indicated in figure 1. The root end of the torsion box was fastened in such a manner that it was practically free to warp. The beam webs were tested as cantilever beams with the load applied at the free end.

TEST RESULTS AND DISCUSSION

The test results are summarized in table 2. The ultimate nominal shear stresses developed by the specimens were calculated by the following formulas:

$$\tau_{ult} = \frac{T_{ult}}{2At} \qquad \text{(for shear webs)}$$

$$\tau_{ult} = \frac{P_{ult}}{h_e t} \qquad \text{(for beam webs)}$$

Predicted failing loads for stiffener crippling, column failure, and web failure are expressed in the table as the nominal shear stress τ, so that strength comparisons may be made between similar webs of different curvatures.

All predicted failing shear stresses shown in the table were calculated for the plane shear webs using the theory of plane diagonal tension given in reference 1; reductions were made to the allowable stress curves in order to provide for the uprights not being attached to the flanges.

Reduced Allowable Stresses

The predicted failing loads for forced crippling failure of the uprights were calculated using 0.7 times the allowable stresses given by the design formulas (13a) and (13b) of reference 1. The predicted failing loads for column failure are based on 0.7 times the allowable column stress obtained by entering a standard column curve using the slenderness ratio L_e/ρ as argument. The reduced "effective" column length L_e is calculated using formula (12) of reference 1.

The predicted failing loads for web failure are based on 0.59 times the allowable web shearing stress given by the upper curve in figure 14(a) of reference 1. The value taken from this curve was corrected to the material properties of the web by multiplying by the ratio of the actual tensile strength of the web to the tensile strength upon which the curve is based. The following web tensile strengths, determined by separate tests, were used: 70.5 ksi for plane shear webs, 71.8 ksi for plane beam webs 1-S and 2-S, and 71.3 ksi for plane beam webs 3-S and 4-S. Observation of the shear and beam webs during the tests showed that, at about two-thirds the ultimate load, a sharp fold developed in the sheet between the ends of the uprights and the flanges. The web failures in most cases were caused by the upright ends punching through the sheet.

Plane Shear Webs and Beam Webs

Ratios of the nominal shear stress at actual failure to the nominal shear stress at the predicted failure for the plane shear webs are given in table 2. Comparison of the predicted with the actual failing loads shows that the strength predictions based on the allowable stresses chosen were conservative except for specimen 1-S which is unconservative by a negligible amount. Table 2 also shows that the ratio of actual to predicted strength for the plane webs ranges from 0.98 to 1.48, only three tests having a ratio larger than 1.4. The average ratio of actual to predicted strength is 1.24. For plane diagonal-tension beams, with uprights connected to the flanges, the corresponding average ratio for a large number of tests is 1.2, and the ratio of 1.4 is exceeded only in a few tests (fig. 22 of reference 1)

Curved Shear Webs

The general problem of cylindrical shear webs is treated in reference 2. Analysis by means of this method, however, gave very poor results (very optimistic strength predictions). The main reason for this failure of the theory is probably the following. In the theory of diagonal tension, the state of stress in the web and in the stiffeners is governed by the shortening of the distance between flanges. If the uprights are connected to the flanges, this shortening is equal to the total shortening of the uprights, which can be calculated. If the uprights are not connected to the flanges, however, the sheet between the end rivet in the upright and the flange buckles badly, and the geometric shortening caused by this buckling becomes much larger than the compressive shortening of the upright. This fact may be expressed by saying that the "effective" upright area is much less than the actual area, and calculation of the effective area would require an extremely difficult analysis of the buckled sheet under the ends of the upright.

Inspection of the experimental values of τ_{ult} for the curved webs disclosed the interesting fact that, aside from scatter of an apparently haphazard nature, these stresses were approximately equal to those for the corresponding plane webs. It is, of course, impossible to predict over what range of parameters this somewhat surprising coincidence will hold. The number of tests appears to be sufficient, however, to make it plausible that, for moderate curvatures such as encountered in wing surfaces (away from the leading edge), the strength of detachable panels of the type considered in this paper can be predicted with reasonable confidence by disregarding the curvature and applying the method described for plane panels. The values given in table 2 show that the average ratio of actual to predicted strength on this basis is 1.23 for the webs with 70-inch radius and 1.15 for the webs with 25-inch radius, while the ratio for plane webs was given before as 1.24. Shear web 6-D-1 had the highest ratio of actual to predicted strength (1.65). Too much weight, however, should not be given to this result because the torque loading frame had insufficient throw and started to bind so that the actual load applied to the specimen was less than the indicated load. Table 2 shows that, if specimen 6-D-1 is disregarded, the minimum ratio of actual to predicted strength for curved specimens was 0.99 and the maximum was 1.41, corresponding ratios for plane specimens being 0.98 and 1.48. The accuracy of prediction for the curved webs is therefore of the same order of magnitude as for the plane webs.

The suggested explanation for the failure of the theory on the curved webs indicates that a more rational method than the one given herein would require not only a modification of the allowable stresses but also a modification of the method of computing the stresses in curved or plane webs with disconnected uprights. Until such a method is developed, the one presented herein may serve as a guide.

CONCLUSIONS

From tests of 39 shear webs which had transverse stiffeners not connected to the flange members, the following conclusions were drawn:

1. The ultimate strength of the plane webs could be predicted by the theory of incomplete diagonal tension after the allowable stresses used in this theory were suitably reduced.

2. The ultimate strengths of the curved webs were essentially the same as those of corresponding plane webs.

3. The consistency of strength predictions for plane or curved webs was about the same as for plane webs in which the stiffeners are connected to the flanges.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., February 18, 1948

REFERENCES

1. Kuhn, Paul, and Peterson, James P.: Strength Analysis of Stiffened Beam Webs. NACA TN No. 1364, 1947.

2. Kuhn, Paul, and Griffith, George E.: Diagonal Tension in Curved Webs. NACA TN No. 1481, 1947.

TABLE 1.- PROPERTIES OF TEST SPECIMENS

Specimen	d (in.)	R (in.)	h (in.) (a)	t (in.)	Uprights (nominal size) (in.) (b)	$\frac{t_U}{t}$	A_U (sq in.)	A_{U_e} (sq in.)	$\frac{A_U}{dt}$	$\frac{A_{U_e}}{dt}$	ρ (in.)	ωd
Plane shear webs												
2-D-0	5.0	∞	23.5	0.0397	$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{16}$	1.62	0.118	------	0.595	0.595	0.224	< 1.0
3-D-0	5.0	∞	23.5	.0394	$\frac{3}{4} \times \frac{3}{4} \times \frac{1}{16}$	1.59	.178	------	.904	.904	.310	< 1.0
4-D-0	5.0	∞	23.5	.0405	$\frac{3}{4} \times \frac{3}{4} \times \frac{3}{32}$	2.32	.264	------	1.31	1.31	.321	< 1.0
5-D-0	10.0	∞	23.5	.0404	$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{16}$	1.55	.118	------	.292	.292	.224	< 1.0
6-D-0	10.0	∞	23.5	.0408	$\frac{3}{4} \times \frac{3}{4} \times \frac{1}{16}$	1.53	.178	------	.436	.436	.310	< 1.0
7-D-0	10.0	∞	23.5	.0410	$\frac{3}{4} \times \frac{3}{4} \times \frac{3}{32}$	2.29	.264	------	.644	.644	.321	< 1.0
8-S-0	5.0	∞	23.5	.0394	$\frac{1}{2} \times \frac{1}{2} \times 0.064$	1.63	.0599	0.0270	.304	.137	.152	< 1.0
9-S-0	5.0	∞	23.5	.0399	$\frac{3}{4} \times \frac{3}{4} \times \frac{3}{32}$	2.35	.132	.0617	.662	.310	.219	< 1.0
10-S-0	10.0	∞	23.5	.0410	$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{16}$	1.53	.059	.0265	.146	.0646	.150	< 1.0
11-S-0	10.0	∞	23.5	.0398	$\frac{3}{4} \times \frac{3}{4} \times \frac{1}{16}$	1.57	.089	.0446	.223	.112	.220	< 1.0
12-S-0	10.0	∞	23.5	.0405	$\frac{3}{4} \times \frac{3}{4} \times \frac{3}{32}$	2.32	.132	.0616	.326	.152	.219	< 1.0
Plane beam webs												
1-S	20.0	∞	23.3	0.0255	$1 \times 1 \times 1 \times 0.072$	2.84	0.192	0.0832	0.377	0.163	0.456	2.4
2-S	10.0	∞	23.3	.0252	$1 \times 1 \times 0.064$	2.57	.116	.0657	.460	.261	.353	1.2
3-S	20.0	∞	23.3	.0252	$\frac{3}{4} \times 1\frac{1}{2} \times \frac{3}{4} \times 0.040$	1.59	.111	.0412	.220	.0819	.587	2.3
4-S	10.0	∞	23.3	.0250	$\frac{3}{4} \times 1\frac{1}{2} \times \frac{3}{4} \times 0.040$	1.61	.111	.0412	.444	.165	.582	1.2

[a] Circumferential length of upright on curved shear webs; length of upright measured between centroids of web-to-flange rivet patterns for plane beam webs.
[b] Uprights on specimens 1-S, 3-S, and 4-S are Z's; all others are angles.

TABLE 1.- PROPERTIES OF TEST SPECIMENS - Concluded

Specimen	d (in.)	R (in.)	h (in.) (a)	t (in.)	Uprights (nominal size) (in.) (b)	$\frac{t_U}{t}$	A_U (sq in.)	A_{U_e} (sq in.)	$\frac{A_U}{dt}$	$\frac{A_{U_e}}{dt}$	ρ (in.)	ωd
Curved shear webs												
1-D-1	5.0	75.3	23.6	0.0388	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.61	0.118	------	0.618	0.618	0.222	< 1.0
2-D-1	5.0	71.8	23.6	.0401	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.56	.178	------	.889	.889	.307	< 1.0
3-D-1	5.0	73.1	23.6	.0390	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.40	.264	------	1.35	1.35	.320	< 1.0
4-D-1	10.0	69.3	23.7	.0398	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.57	.118	------	.296	.296	.222	< 1.0
5-D-1	10.0	67.4	23.7	.0396	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.58	.178	------	.450	.450	.307	< 1.0
6-D-1	10.0	68.8	23.7	.0398	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.36	.264	------	.663	.663	.320	< 1.0
1-S-1	5.0	73.0	23.6	.0390	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.60	.059	0.0265	.303	.137	.150	< 1.0
2-S-1	5.0	71.7	23.6	.0398	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.57	.089	.0446	.447	.225	.220	< 1.0
3-S-1	5.0	71.4	23.6	.0392	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.39	.132	.0616	.673	.315	.219	< 1.0
4-S-1	10.0	73.8	23.6	.0396	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.58	.059	.0265	.149	.067	.150	< 1.0
5-S-1	10.0	77.3	23.6	.0399	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.57	.089	.0446	.223	.112	.220	< 1.0
6-S-1	10.0	69.9	23.6	.0396	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.37	.132	.0616	.334	.156	.219	< 1.0
1-D-3	5.0	24.5	24.6	.0399	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.57	.118	------	.592	.592	.222	< 1.0
2-D-3	5.0	24.1	24.6	.0401	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.56	.178	------	.889	.889	.307	< 1.0
3-D-3	5.0	24.2	24.6	.0400	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.34	.264	------	1.32	1.32	.320	< 1.0
4-D-3	10.0	24.8	24.6	.0398	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.57	.118	------	.296	.296	.222	< 1.0
5-D-3	10.0	24.5	24.6	.0397	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.57	.178	------	.448	.448	.307	< 1.0
6-D-3	10.0	25.0	24.5	.0405	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.31	.264	------	.652	.652	.320	< 1.0
1-S-3	5.0	23.2	24.7	.0401	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.56	.059	.0265	.295	.133	.150	< 1.0
2-S-3	5.0	25.0	24.5	.0398	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.57	.089	.0446	.447	.225	.220	< 1.0
3-S-3	5.0	23.9	24.6	.0415	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.26	.132	.0616	.637	.297	.219	< 1.0
4-S-3	10.0	25.8	24.5	.0406	$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{16}$	1.54	.059	.0265	.146	.066	.150	< 1.0
5-S-3	10.0	25.7	24.5	.0403	$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{16}$	1.55	.089	.0446	.221	.111	.220	< 1.0
6-S-3	10.0	25.4	24.5	.0398	$\frac{3}{4}\times\frac{3}{4}\times\frac{3}{32}$	2.36	.132	.0616	.332	.155	.219	< 1.0

[a]Circumferential length of upright on curved shear webs; length of upright measured between centroids of web-to-flange rivet patterns for plane beam webs.
[b]Uprights on specimens 1-S, 3-S, and 4-S are Z's; all others are angles.

TABLE 2.- TEST DATA AND RESULTS

Specimen			Calculated τ_{cr} (ksi)	k	Experimental τ_{ult} (ksi) (a)			Predicted $\tau_{R=\infty}$ (ksi)			$\frac{\text{Experimental } \tau_{ult}}{\text{Predicted } \tau_{R=\infty}}$ (e)		
$R = \infty$	$R \approx 70$	$R \approx 25$			$R = \infty$	$R \approx 70$	$R \approx 25$	τ_1 (b)	τ_2 (c)	τ_3 (d)	$R = \infty$	$R \approx 70$	$R \approx 25$
Double uprights													
2-D-0	1-D-1	1-D-3	6.41	0.23	18.8U	17.8U	19.5W	20.9	27.9	17.8	1.06	0.99	1.10
3-D-0	2-D-1	2-D-3	6.91	.27	24.0W	25.4W	18.4W	26.7	53.7	18.1	1.33	1.39	1.02
4-D-0	3-D-1	3-D-3	8.27	.24	24.8W	22.9W	21.3W	39.2	71.9	18.7	1.33	1.22	1.13
5-D-0	4-D-1	4-D-3	1.50	.44	12.9U	14.8U	15.4W	12.1	14.4	16.4	1.07	1.22	1.27
6-D-0	5-D-1	5-D-3	1.64	.51	21.6U	18.8W	17.4W	14.6	26.8	17.2	1.48	1.29	1.19
7-D-0	6-D-1	6-D-3	1.86	.50	22.9W	[f]27.3W	16.8W	21.8	34.8	16.6	1.38	1.65	1.01
Single uprights													
8-S-0	1-S-1	1-S-3	4.33	0.27	15.3U	14.7U	13.0U	13.0	----	17.4	1.18	1.13	1.00
------	2-S-1	2-S-3	----	----	----	16.2U	17.8U	14.0	----	17.3	----	1.16	1.27
9-S-0	3-S-1	3-S-3	4.86	.30	19.5U	19.6U	19.4W	19.2	----	17.6	1.11	1.11	1.10
10-S-0	4-S-1	4-S-3	1.19	.43	9.73U	10.3U	9.22U	8.7	----	16.1	1.12	1.18	1.06
11-S-0	5-S-1	5-S-3	1.14	.49	13.2U	11.2U	13.7U	9.72	----	16.2	1.36	1.15	1.41
12-S-0	6-S-1	6-S-3	1.29	.50	15.3U	16.1U	16.1W	12.5	----	16.1	1.22	1.29	1.29
1-S	----	----	.191	.73	12.6W	----	----	12.9	----	13.5	.98	----	----
2-S	----	----	.525	.64	16.6W	----	----	15.0	----	15.7	1.11	----	----
3-S	----	----	.170	.73	11.4U	----	----	7.8	----	13.4	1.46	----	----
4-S	----	----	.483	.63	14.7U	----	----	10.1	----	15.8	1.45	----	----
										Average =	1.24	1.23	1.15

[a]U indicates observed upright failure; W indicates observed web failure.
[b]For forced crippling failure of plane webs.
[c]For column failure of plane webs.
[d]For web failure of plane webs.
[e]Predicted $\tau_{R=\infty}$ is the lowest one of the predicted stresses, τ_1, τ_2, and τ_3.
[f]Load too high; torque loading-frame binding.

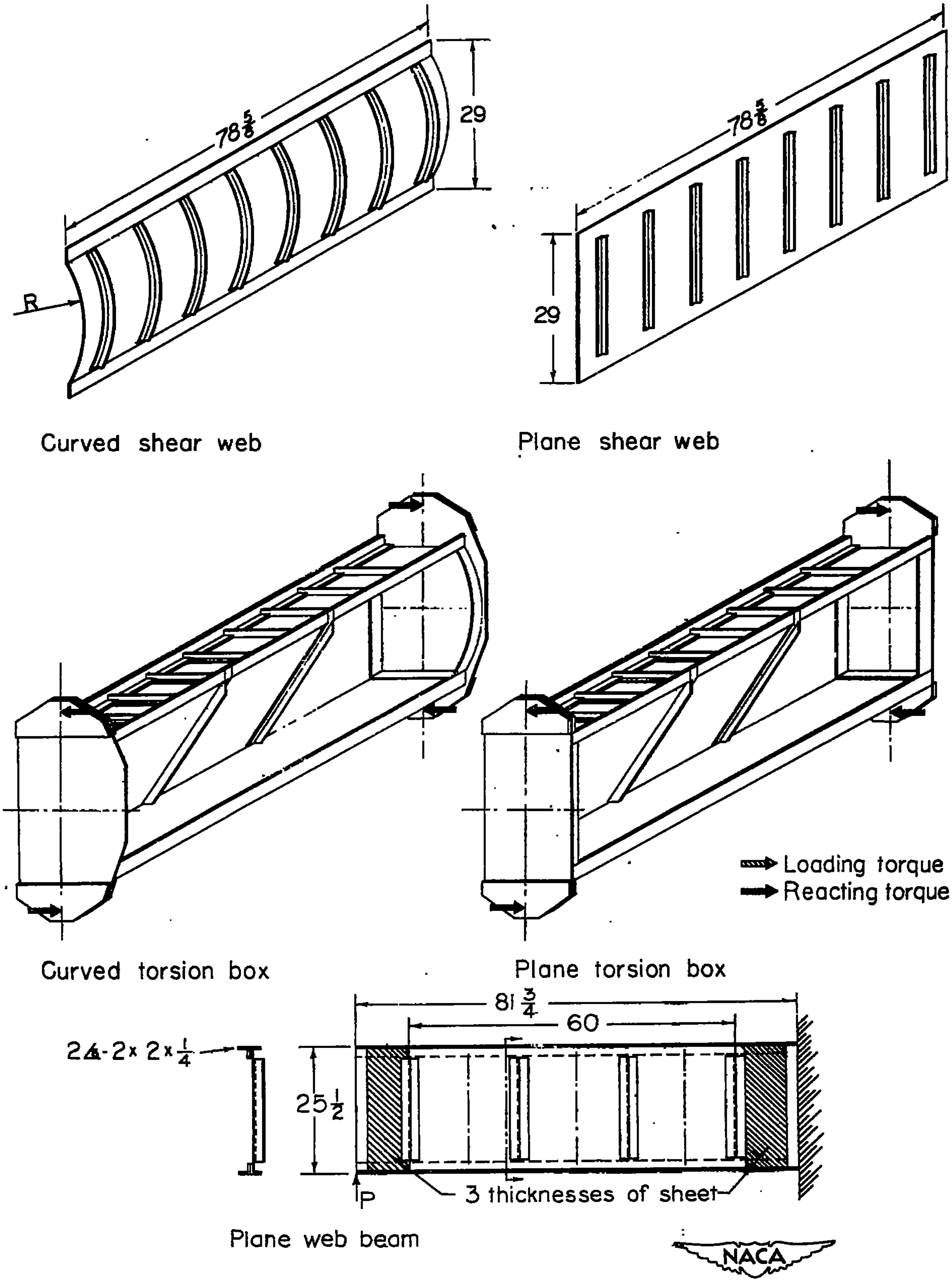

Figure 1.- Dimensions of test specimens.